Methodology, Data Requirements, and Metrics for Defining System Lifetime and Life-Cycle Costs

Introduction

The Department of Energy's National Photovoltaics Program Five-Year Plan is clear in its definition of tasks for the nation's research centers. These key tasks are[1]:

- Making dependable PV devices that convert sunlight to electricity efficiently.
- Developing a strong scientific base to ensure the continued technical progress that will enable PV cost to become competitive for large, price-sensitive energy markets.

These tasks support the goals of the National Program to "accelerate the development of PV as a national and global energy option and to ensure U.S. technology and global market leadership." Following these directives, Sandia National Laboratories (SNL) and its strategic partners have begun a **multi-year project** "to determine the reliability of systems in the field – how long they last, how well they perform during their lifetime, and how much maintenance they need."[2] This project centers around the development of an accurate, capable **reliabilitydatabase** of fielded PV systems.

The **reliability database** will be the principal tool used to define two important parameters necessary for enhanced market development and growth: ***PV system lifetime*** and ***PV system life-cycle cost (LCC)***. At the same time, analysis of the data is expected to identify the critical steps needed to improve lifetime and reliability in fielded PV systems. Improving lifetime and reliability will contribute to lower cost and accelerated market growth for PV systems.

Methodology, Metrics and Data Requirements of the Project

The **methodology** used to define system lifetime and life-cycle costs is a multi-step process, as illustrated in Figure 1. This process requires sets of data from fielded PV systems and the development of a sophisticated database tool for analysis of the data. Together, the data and database will support the long-term goal of defining the **metrics** of ***system lifetime*** and ***system life-cycle cost***. The need for these **metrics** by builders, developers, utilities, industry, and the public grows as PV systems become more and more widely used in the United States. System lifetime and LCC determine where PV can be cost-competitive with other energy options, where PV is the logical choice, and how new PV markets will develop.

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[1] ***Photovoltaics: Energy for the New Millennium***, the National 2000-2004 Photovoltaics Program Plan, U.S. Department of Energy.
[2] *Ibid.*

For this project to be successful, the **data requirements** are rigorous. Figure 2 provides an example of requirements for a solar home lighting system. To be considered for the project, all candidate data sets must contain entries for three basic categories: (1) non-technical system attributes (e.g. location, owner, purchase price, installation training, documentation); (2) technical component specifications (e.g. manufacturer, model, rating); and (3) maintenance and repair records (e.g. failures, replacement costs, regular maintenance frequency and description, labor costs). Tables of PV system statistics are not new, but in one critical respect, this project is unique by recognizing the importance of maintenance records as an integral part of the database.

To accurately model system lifetime and costs, large, complete data sets are required. Unfortunately, few PV deployment programs have combined large numbers of systems with regular record keeping. And, where records have been kept, they are often incomplete. In the last year Sandia competed several small contracts which included a variety of PV integrators/owners. These partners provided pilot data from solar home lighting, water pumping and grid-tied systems. In an iterative approach typical components and component attributes were defined for each of these applications. Also, consensus was attained on defining how the components typically failed. This agreement on system failures led to failure modes being defined that are a critical part of the database. This work has provided guidance in the process of collecting data, database design and data analysis. With this experience as a guide the project is working to establish record-keeping processes for future collaboration. Work is now underway with the Florida Buildings Program and the Navajo Tribal Utility Authority (NTUA). Here strategic partnerships have been developed early that allow Sandia to support the needs of Florida Solar Energy Center (FSEC) and NTUA while also meeting rigorous data and maintenance record-keeping requirements.

As indicated in Figure 1, development of the database and analysis concepts is an iterative process. Here Sandia's experience of the previous year has provided a pilot database and starting points for analyis. Analysis of the data is to be used to identify trends in the data related to failure rates and incurred costs (e.g., first, O&M, etc.). This failure and cost information will, in turn, provide direction for improving the database design and analysis concepts, in addition to supporting the effort to quantify system lifetime and LCC.

Using this failure and cost information, a key goal is to develop a process for quantifying system lifetime and LCC. Although the analysis work will provide input to quantify system lifetime and LCC, these efforts will culminate in providing information to builders, developers, utilities, industry, and the public on steps necessary to improve system lifetime and LCC.

Project Partners

Functionally, all PV systems fall into one of two categories: those systems connected to the utility grid (grid connected), and those not connected to the grid (grid independent). In this project, these two PV system categories are considered separately and the metrics related to system costs will be determined for each. A strategic partner has been selected in each category. FSEC, through its implementation of the Florida PV Buildings Program, is providing data and support in the area of grid-connected systems. In addition, the Southwest Technology Development Institute (SWTDI), through its partnership with the NTUA, is providing data and support in the area of grid-independent residential systems.

FSEC and the Florida PV Buildings Program

FSEC, through their implementation of the Florida PV Buildings Program, will conduct a variety of application experiments to field systems over the next decade. This effort is focused on gathering information that will help define the costs, value and benefits of using photovoltaic energy. Here the work is to develop database formats and the first version of the investigative analyses available to the user. This involves determining what information is most relevant and practicably attainable. The main objective is to create a skeleton database that functions properly and has the most fundamental data inputs and outputs available, while allowing users to search for information in a straight-forward manner.

The database will be broken into three main categories: performance, reliability, and cost. Performance will include data such as average daily energy (ac and dc), average efficiencies for the array, inverter, and system, array temperatures, ratios of system output to insolation, array rating, array surface area, and ratios of building load to energy from the PV system.

The reliability portion of the database will consist of data that will help evaluate a system's success. Factors such as system downtime, average time between failures, seriousness of failure, aggregate information for components (e.g., inverters, modules, wiring, etc.) will be included. A maintenance log updated by the system owner will also be available with appropriate database access.

The final section of the database will account for the costs, benefits, and value of a system. Figures will be gathered to gauge expenditures and the number of labor hours spent for installation, operation, and maintenance. Analyses of non-economic factors will be available, relating system output to environmental and disaster mitigation benefits.

SWTDI and the NTUA Off-Grid Residential PV Program

SWTDI has been working closely with the Navajo Tribal Utility Authority in its implementation of a large program of deployment of grid-independent, residential PV power systems.

The NTUA (Ft. Defiance, Arizona) is responsible for providing electric power to the residents of the 26,000 square mile Navajo Nation. NTUA believes that PV is the cost-effective option for providing electricity to many of its remote areas. NTUA purchased 100 stand-alone residential PV power systems in 1999 (and another 100 in 2000) for installation at remote homes throughout its service area. From the beginning, Sandia and SWTDI have been supporting the NTUA in all facets of this wide-scale program. This support has included system design evaluation, installer training, field test and evaluation, system performance monitoring and development of maintenance schedules, procedures and record-keeping forms.

The support for NTUA has been designed around one primary goal: the successful deployment of properly installed, maintained, and operated PV systems. Support has also been structured with the requirements of the reliability database in mind. For example, the program partners helped NTUA develop maintenance forms that meet their requirements. Also, Sandia/SWTDI support has included ten low-cost data acquisition systems. These monitoring systems provide valuable records of how the PV systems are being used. In the short term, these monitoring systems provide data useful for troubleshooting system problems, while in the long term, the data monitoring may provide information on the relationship between system use and system lifetime.

Based on PV customer satisfaction, the partnership among NTUA, Sandia, and SWTDI is already a success. The continued record keeping by the NTUA electricians of system performance, component failure rates and replacement, and maintenance costs will provide an invaluable resource for the derivation of accurate lifetime and LCC of grid-independent PV power systems.

Conclusion

The goals of the DOE PV Program are to accelerate the development of PV as a national and global energy option and to ensure U.S. technology and global market leadership. The support of these goals is accomplished through documenting the methodology, data requirements and metrics to define system lifetime and life-cycle cost. The reliability databases for grid-connected and grid-independent PV systems are one approach Sandia National Laboratories is using to establish accurate PV system lifetime and system life-cycle cost. Analysis using the database is expected to lead to identification of trends in fielded systems. Study of these trends can lead to improved understanding of system lifetime and life-cycle cost by exposing general design weak points or common problems. The database and its supporting work will help document the performance of fielded systems that, in turn, will improve systems engineering efforts. Benefits to the PV industry will be improved returns on their investment through better designs and more fielded systems.

At present (summer 2000), a pilot database exists and work continues in the tasks of data entry and analysis. The effort is an ongoing project where data from additional families of installations is continually sought. As data is acquired the future work will focus on efforts to quantify system life-cycle costs. Here, an approach being considered is the development of a model for life-cycle costs. An application will be to chosen where quality data is available . As input parameters are identified, the database tool (with its analysis capability) will be used to provide this information as appropriate. This project is considered to be a long-term investment that will provide trend information in the short term (1-5 years) from which quantitative results will follow in the longer term (5-10 years).

Figure 1: Methodology for Defining System Lifetime and Life-cycle Costs

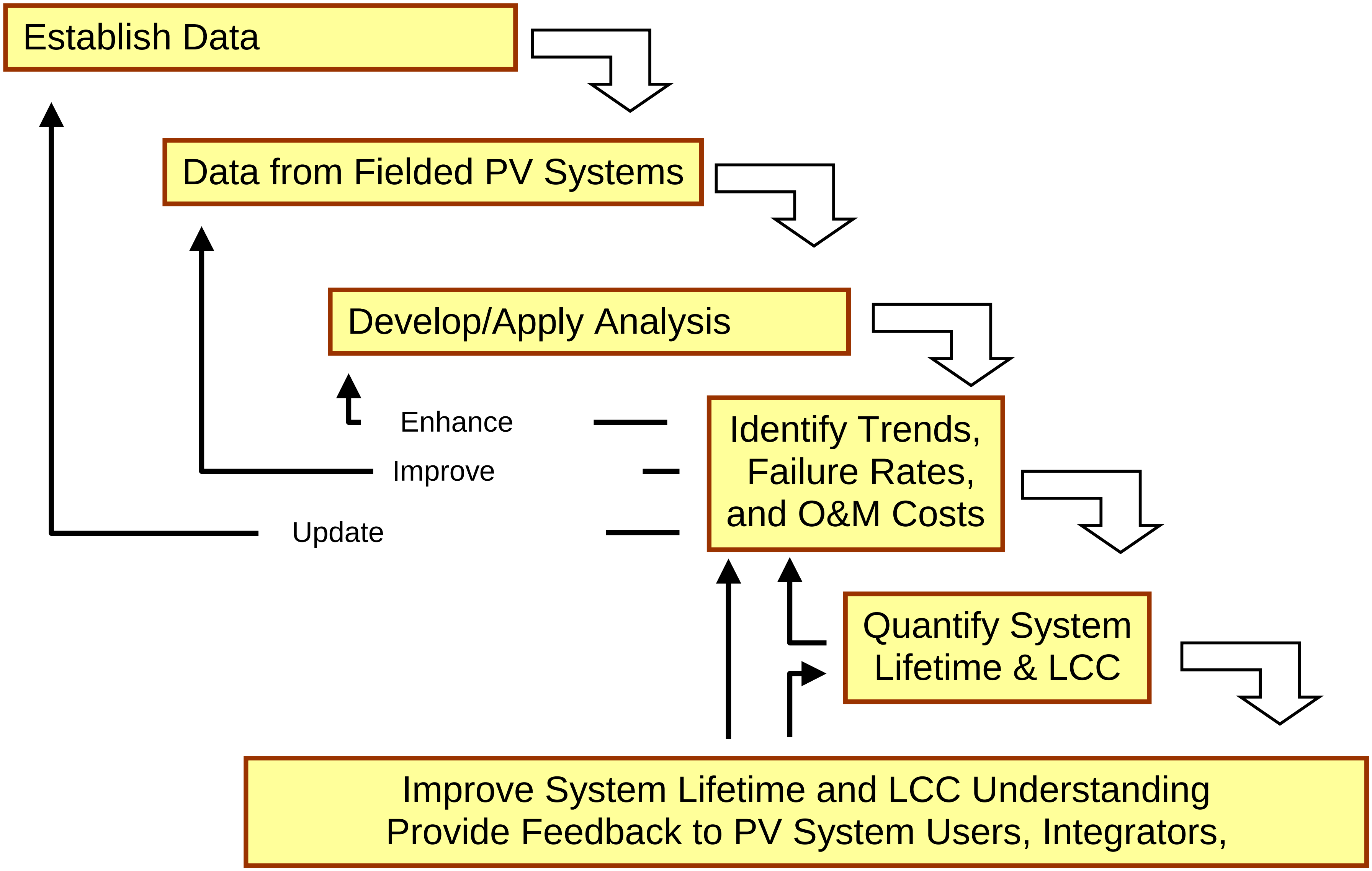

Figure 2: Data Requirements in a Solar Home Lighting

System

System Table
- System ID
- Program ID
- User Training
- User Manual
- Application
- Integrator
- Array Size
- Customer
- Street Address
- Street Name
- City
- County
- State
- Country
- Location
- Latitude Degree
- Latitude Mins
- Latitude Secs
- Longitude Degrees
- Longitude Mins
- Longitude Secs
- Install Date
- Retire Date
- Monitoring Star Date
- Initial Cost Sys
- Expected Cost
- Recovery
- Installation Rep
- Comment
- Utility Name
- User ID
- Entry Date

Component

Battery Table
- System ID
- Component ID
- Program ID
- Manufacturer
- Model
- Serial Number
- Install Date
- Retire Date
- Type
- Style
- User ID
- Entry Date

PV Module Table
- System ID
- etc……..

Charge Controller Table
- System ID

Lamp Table
- System ID
- etc……..

Light Fixture Table
- System ID
- etc……..

Maintenance

Maintenance Table
- System ID
- Component ID
- Program ID
- Maintenance ID
- Component Code
- Routine Maintenance
- Maintenance Rep
- Failure Date
- Failure Reported
- Return to Service Date
- Replaced Date
- Action Taken
- Failure Mode
- Cost Parts
- Cost Labor
- Cost Travel
- Cost Hours
- Downtime
- Comments

Note:
-Battery Table shown in detail
-Comparable detail available for